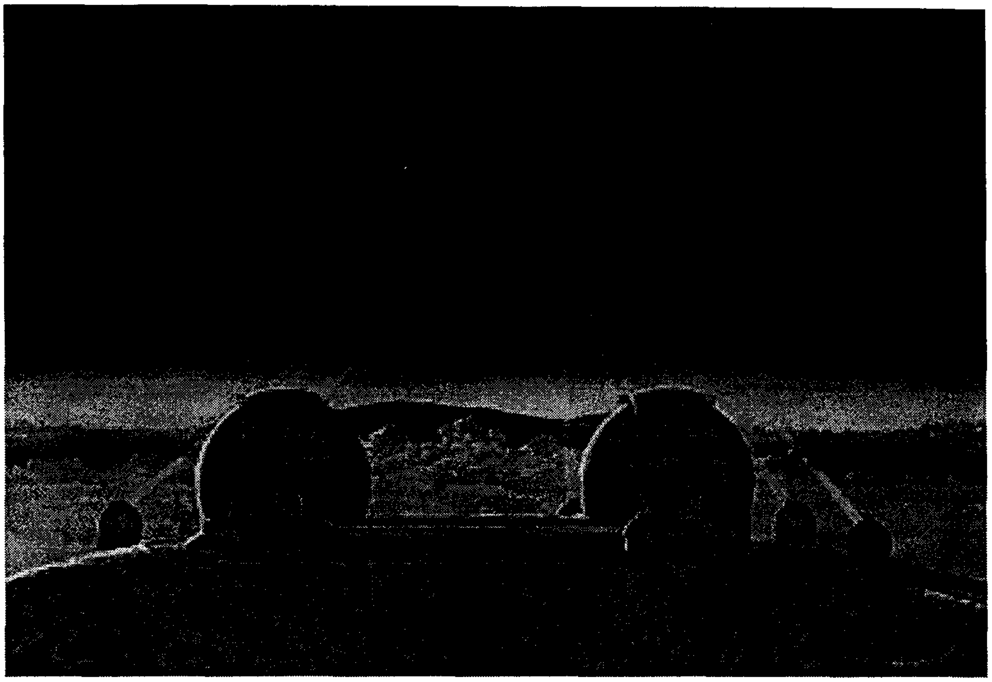
How Can Wave Behavior Help Us Find Planets Around Distant Stars?



Artist's concept of NASA's giant Keck Telescopes on the Big Island of Hawaii, with proposed outrigger telescopes that will create the Keck Interferometer.

We experience wave behavior in everyday life. Wind makes waves on water. Sound travels in waves through the air. We cook using microwaves. We listen to music carried by radio waves. We are immersed in a sea of electromagnetic waves that we call light. By observing how waves behave, scientists have learned more about the universe than we ever imagined. Fundamentally, the entire science of astronomy is based on our understanding of how and why waves behave the way they do.

Here we will see how waves act in water. We will also see how the same kinds of wave behavior occur in other everyday situations. We can thus begin to understand waves and how scientists use wave interference patterns to learn about planets and stars.

As part of its Origins Program, NASA is planning the construction of the Keck Interferometer on Mauna Kea, Hawaii. This pair of giant telescopes, combined with several proposed "outrigger" mirrors, will greatly enhance our ability to detect planets around other stars. When you have read this article and finished the activity, you will have begun to understand the basic physical principles upon which such advanced telescopes are based.

Light: Particle or Wave? Particle AND Wave!

Quick, go to the light switch and turn out the lights. When the lights are out, the room is empty of light—at least from that light source. Flip the switch, and the room is filled with light again. How fast did the light travel from the light source (the incandescent light bulb or fluorescent light tube) to the walls of the room? Faster than we can blink. Faster than we can snap our fingers. And how did it get from the light source to fill the room? Did it come out of the light source in chunks, or did it flow in waves? These simple questions defy easy answers.

Even though we are immersed in light, it is not easy to really see what it is and how it works. Our senses cannot measure the speed or composition of light. Scientists in the late 19th and early 20th centuries made significant technological breakthroughs, inventing instruments to observe and measure the characteristics of light.

At first, scientists who wished to measure light tried to figure out whether light came in particles or waves. We have learned that light is both. We can observe that light travels in *photons*, separate little packets, or *quanta*, of energy that we can measure. We also measure photons in terms of their wave motion, in units of *wavelength* and *frequency*.

Traffic Waves

Imagine ten cars lined up at a red light. Theoretically, if all ten drivers are wide awake and see the light turn green at the same instant, all ten cars could start to move simultaneously. But what really happens is that the first car gets going, then the second car gets going, then the third car gets going—in effect, a wave of getting going moves through the row of cars. If you're in the tenth car, you'll be lucky to get going before the light turns red again!

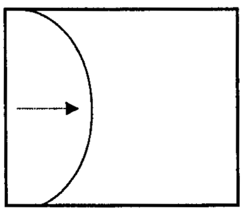
A similar effect can be noticed as cars approach a curve on a crowded freeway. As "photons" of cars slow down, a wave pattern of slowing and speeding up again affects the traffic movement as a whole.

Water Waves

Pour some water into a shallow, transparent, rectangular dish (plastic or glass). Rest your hand on one edge of the dish--the narrower end if the dish is oblong. Suspend one finger over the water.

Make sure the water is still, free of any vibration.

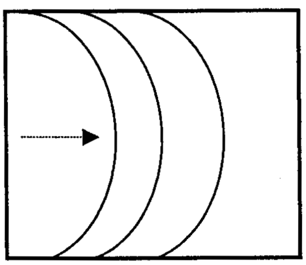
Now, gently tap your finger into the water.



A wave is created—you can see it—that travels as an arc of a circle across the water in the dish.

One tap, one wave front. (It may help to shine a bright light on the water.)

Now, try a series of taps, setting up a series of successive wave crests.



In the case of these waves, the finger-tapping sets off a series of compressions (the finger pressing down on the water) and decompressions (the finger pulling out of the water) that set off waves that travel through the water. We can see the basic structure of waves even in this simple experiment. Compressing the water causes nearby water to rise up into a *crest*; decompressing causes nearby water to drop down into a *trough*. This crest-trough structure defines the features of the wave. One wave is one crest plus one trough. The distance from crest to crest (or trough to trough) is the wavelength. The number of waves within a defined time span (for instance, waves per second) is the frequency. The particular part of a wave (its crest or trough, for example) passing a certain point at a certain time is called the *phase* of the wave.

Now, one intriguing feature of wave behavior is what happens when waves from different sources cross each others' paths. Wave patterns *interfere* with each other. Some basic interference patterns can be observed with our simple water experiment.

Opposing Waves

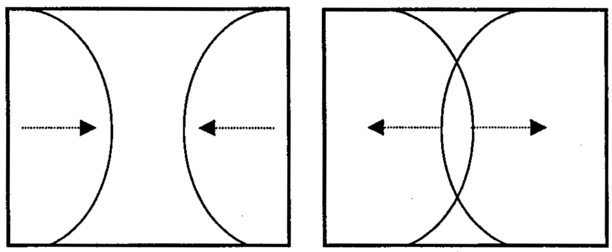
Place hands on opposite edges of the dish.

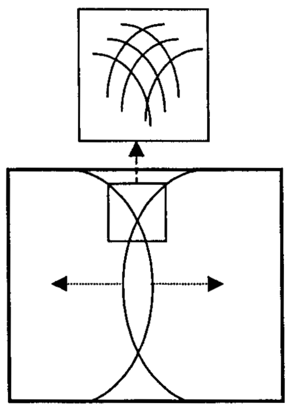
Suspend one finger from each hand over the water.

Tap both fingers into the water at the same time.

What do you see?

Two arcs cross over each other, each moving the opposite direction. Arc paths cross at two points, as they move across each other.



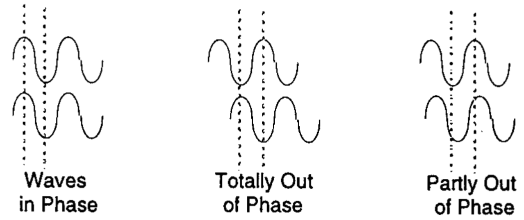


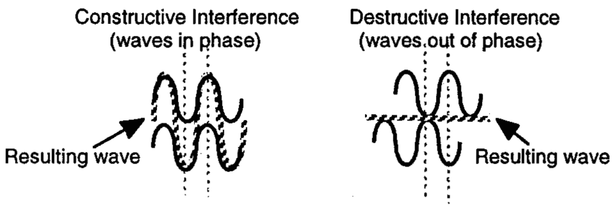
Now look closely at the area just beyond the crossing point. You will notice a mottled patch of diamond-shapes rippling across. These are places where interference is taking place.

Constructive interference occurs when two troughs or two crests, one from each wave front, match up in phase, and add on to each other.

Destructive interference occurs where a trough and a crest match up out of phase, in effect cancelling each other out.

As wave fronts interact, constructive and destructive interference creates characteristic patterns. Understanding



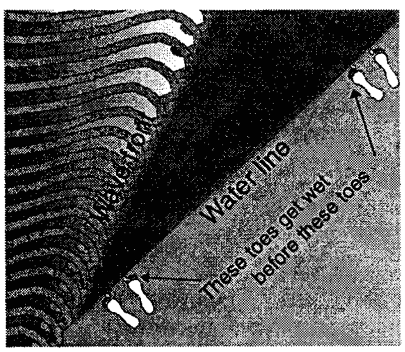


wave behavior through the observation and measurement of interference patterns is called *interferometry*.

Now, we can return to the problem of observing and measuring the characteristics of light. Once it became clear that light travels in waves, scientists were able to think of ways to observe and measure its wave behavior. From there, they realized they could use these discoveries and techniques to learn a lot about the objects (such as stars and planets) that produce or reflect the light.

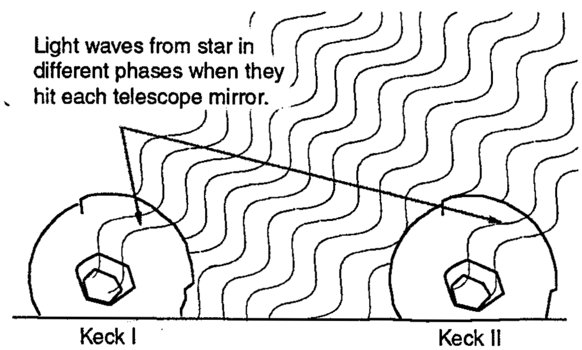
The Keck Interferometer

Scientists can observe and measure light's wave behavior using interferometry. A star shines its light toward Earth. Like ripples on a pond, except in three dimensions, the light spreads out from the star in a sphere. But, because the distance is so great, each wave front is, for all practical purposes, flat rather than rounded by the time it reaches Earth.



Think of ocean waves crashing against a wide stretch of beach. The waves seldom hit the beach straight on. They usually come in at some angle. Imagine two people standing a few meters apart with their toes on the highest place the sand got wet from the last wave. The next wave will get one person's toes wet before the other person's.

Atop Mauna Kea, an extinct volcano on the "Big Island" of Hawaii, two giant telescopes sit 85 meters apart. Each telescope's mirror points toward the same star, but greets the wave front coming from that star at slightly different times. So the wave that Keck I sees will be slightly out of phase with the wave Keck II sees. Because the star is very far away though, the difference will be very tiny. (Our drawing below is quite exaggerated.) The telescopes include a lot of other equipment and computer programs that combine the images from the two telescopes, analyze the interference patterns, and, using that information, figure out with great precision the exact position of the star and its size.



Why is it so interesting to know the exact position of a star? If we can measure its position accurately enough, we can see whether or not the star "wobbles" even by a few meters over a period of days, weeks, or months. If a star wobbles, it means a good-sized planet is probably in orbit around it, and the gravity of the planet is tugging on the star a little bit. From the amount of wobbling and how long it takes to move back and forth, we can tell the size of the planet and how long it takes to orbit the star, and, from that, we can calculate how far the planet is from the star. This method of planet detection is called *astrometry* (*"astro"* means star, and *"metry"* means measuring).

The farther apart the two telescopes, the better the resolution of their combined image. However, if the line between the telescopes (called the *baseline*) runs east and west, the position of the star will be known precisely only in the east-west dimension. If two more telescopes could be placed along a north-south baseline, the precise position of the star could also be known in the north-south dimension. Since the two Keck Telescopes are along (more or less) an east-west baseline, two more telescopes positioned along a north-south baseline would give valuable additional information about the star's position and size. The more images combined from along different baselines, the better the resolution. The National Aeronautics and space Administration (NASA) has proposed to add four additional "outrigger" mirrors to the two giant Keck Telescopes, to create the Keck Interferometer. The Keck Interferometer will be used to look for planets outside our solar system. Besides astrometry, it will use two other techniques to look for planets.

We want to find out about planets in other solar systems, so we can learn more about our own solar system and maybe begin to answer the question "are we alone in the Universe?"